Orbiting Astrophysical Spectrometer in Space (OASIS)

Presented by Jim Adams for the OASIS collaboration

ENTICE

(Energetic Trans-Iron Composition Experiment)

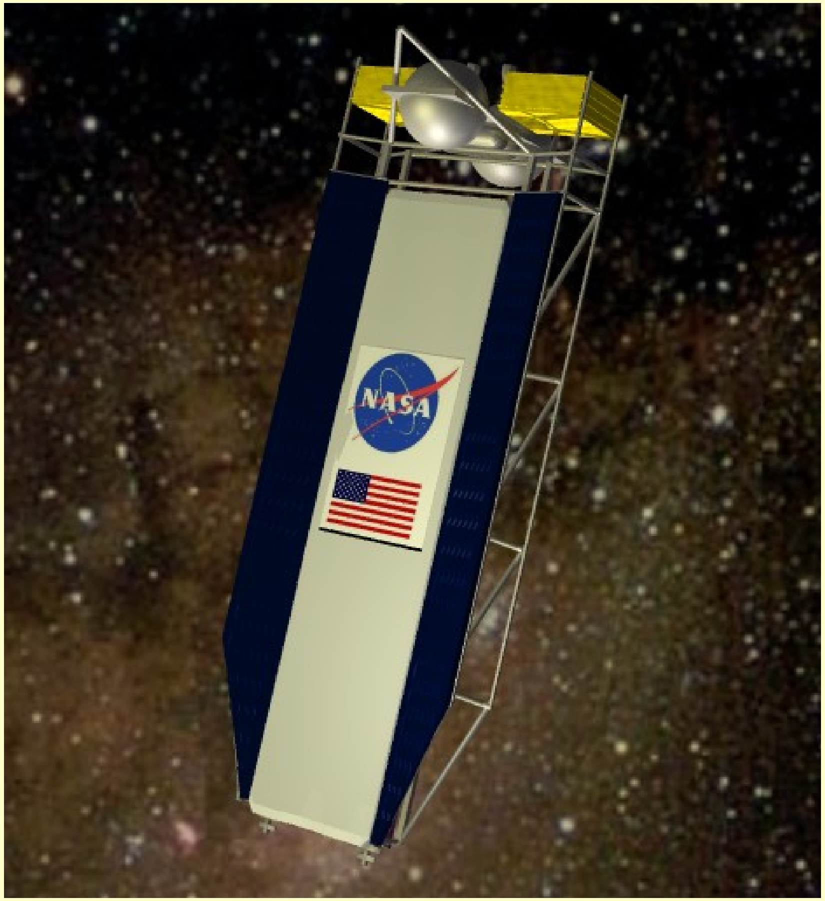
Wash. U.

Caltech

JPL

GSFC

MSFC



HEPCaT

(High Energy Particle Calorimeter Telescope)

GSFC

LSU

NMSU

MSFC

Three year mission in a sun-synchronous orbit

Introduction to Cosmic Rays

- Charged particles (electrons, atomic nuclei)
  - Strongly deflected by interstellar magnetic fields
  - Most cosmic rays arrive isotropically
  - ➢ <u>They do not point back to their sources</u>
- Cosmic rays are a major feature of our Galaxy
  - Cosmic ray energy density is 1.8 eV/cm^3
  - Approximately the same as the energy density in:
    - Interstellar magnetic field
    - Turbulent motions of the interstellar gas
    - Total electromagnetic energy density in the Galaxy

How are they accelerated?

- Probably Energized by Supernovae
  - Residence time in the galaxy $\approx 2.6\text{x}10^7$ yrs
    - Power required $\sim 2.5\text{X}10^{47}$ ergs/yr
  - A Type II Supernova yields $\sim 10^{53}$ ergs
    - But only 10^{51} ergs in the blast wave
  - SN rate $\approx$ 2/century $\approx 2\text{X}10^{49}$ ergs/yr
    - Blast wave must convert ~1% of its energy into cosmic rays.
- Circumstantial evidence but not a proof!

OASIS Objectives

- **OASIS will Answer Important Scientific Questions about GCRs**
  - Do GCRs Come from OB associations?
  - Where does the GCR electron end?
    - Does a single local source dominate at the highest energies?
  - What is the physical state of the material injected into the cosmic ray accelerators?
  - Are Z=1 and Z>1 GCRs from different sources?
- **And Produce Other Results**
  - Nucleosynthesis: Determine nucleosynthetic origin of ambiguous elements (e.g., Pb, Bi)
  - Search for superheavy elements
  - Search for evidence of dark matter (Kaluza-Klein particles)

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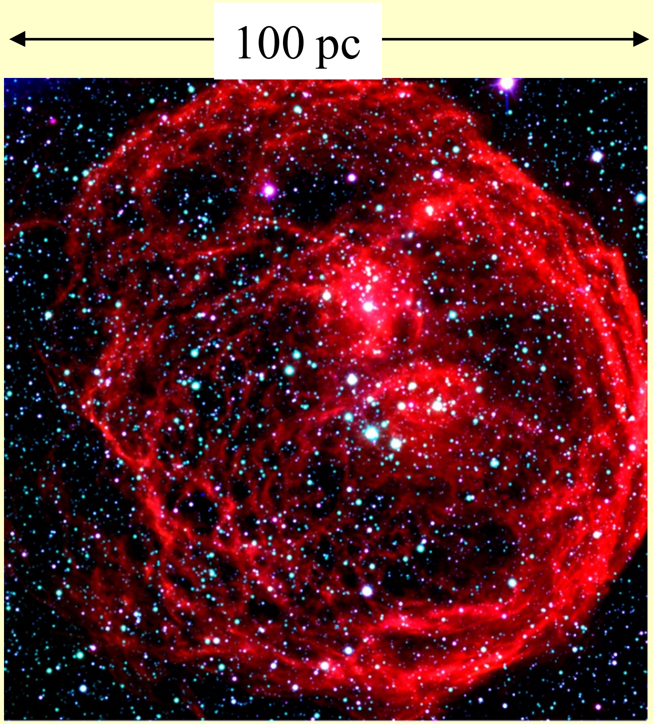
Ultraheavy GCR measurements with ENTICE will:

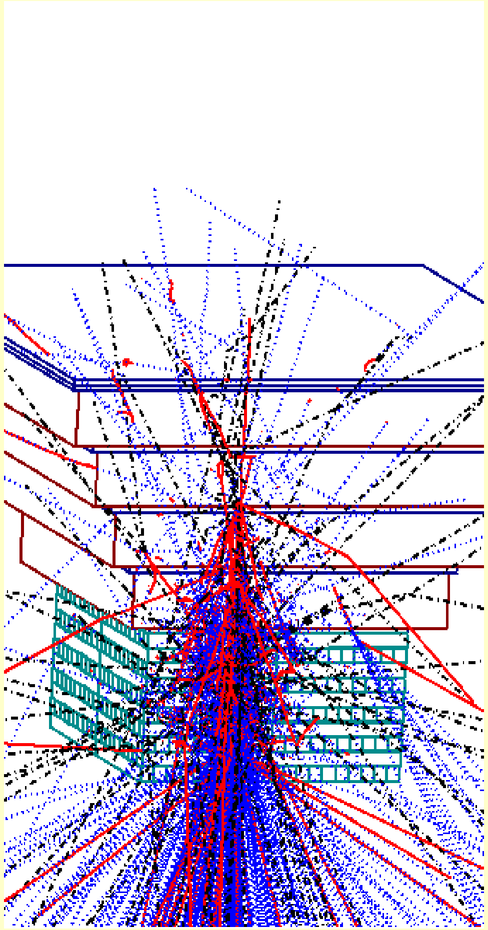
- **Measure the relative abundances of the heaviest cosmic rays**
  - The elemental abundance pattern will identify the site of injection into the accelerator.
    - OB associations?
    - Cold Interstellar Medium (dust and gas)?
    - Warm stellar atmospheres?
- **If freshly synthesized material is found, it would indicate supernova acceleration in OB associations.**
  - SN shocks in superbubbles formed by OB associations are thought to accelerate the local interstellar material from recent SN and stellar winds.
  - This would establish cosmic rays as a sample of the material from which stars are currently being formed.
  - Cosmic Rays would tell us the production ratios of heavy nuclei in supernovae.
- **Bonus Science--Superheavies**
  - Search for superheavy elements



Superbubble (N 70) in the Large Magellanic Cloud
(ESO Very Large Telescope Image)

HEPCaT will search for:

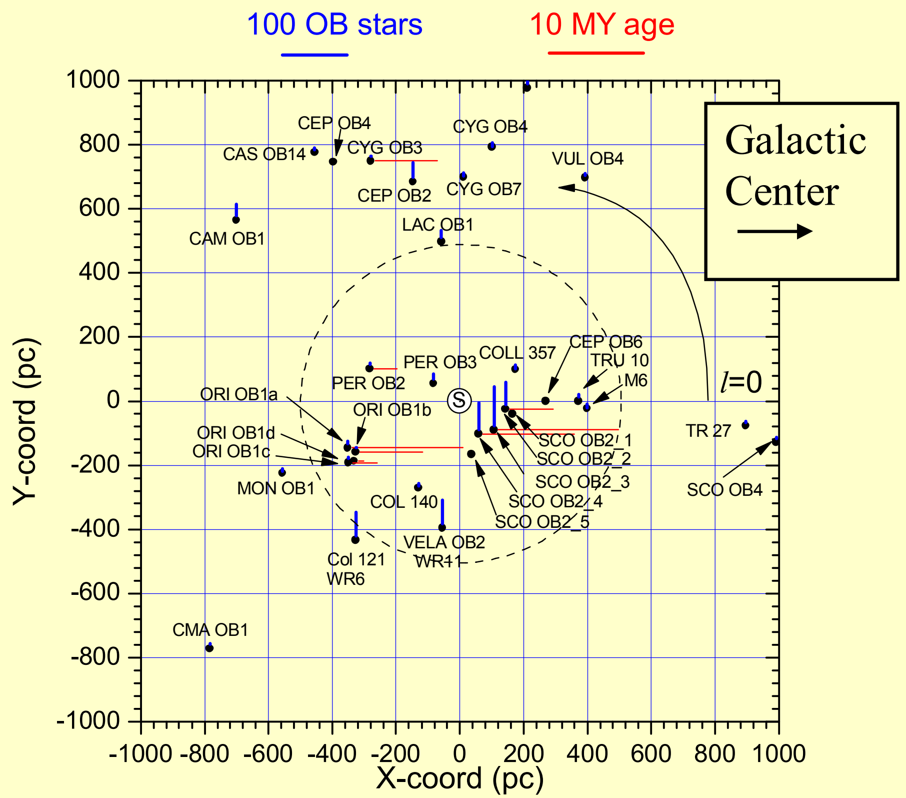
- The end of the electron spectrum where electrons are coming only from the nearest source
  - To look for structure and to identify this source
  - If the nearest source can be identified:
    - The CR diffusion coefficient can be measured.
    - This source can be studied as an example of a CR accelerator.
- A signature of the nature of dark matter
- Composition changes at the highest energies (accessible to direct measurement) due to:
  - The growing dominance of more massive stars or
  - Non-standard compositions in young OB associations
- A lower bound to the B/C ratio, indicating the GCR sources are shrouded
- Evidence of GCR re-acceleration



Galactic Cosmic Rays – the Youngest Accessible Sample of Matter

A very fresh (< 10 Myr) sample should be present in galactic cosmic rays (Higdon & Lingenfelter, 2003 ApJ; Binns et al., 2005 ApJ)

- The majority of core collapse SN (80-90%) in our galaxy occur in OB associations
- SN shocks accelerate ambient material in OB association
- Mean time between SN in OB associations is ~1 Myr
- Superbubbles are enriched in freshly-synthesized, rapid neutron capture (r-process) material from SN ejecta (Streitmatter et al, 1985)



Vertical blue& red bars represent the number of OB stars in the association and the association age (in MY) respectively. l (

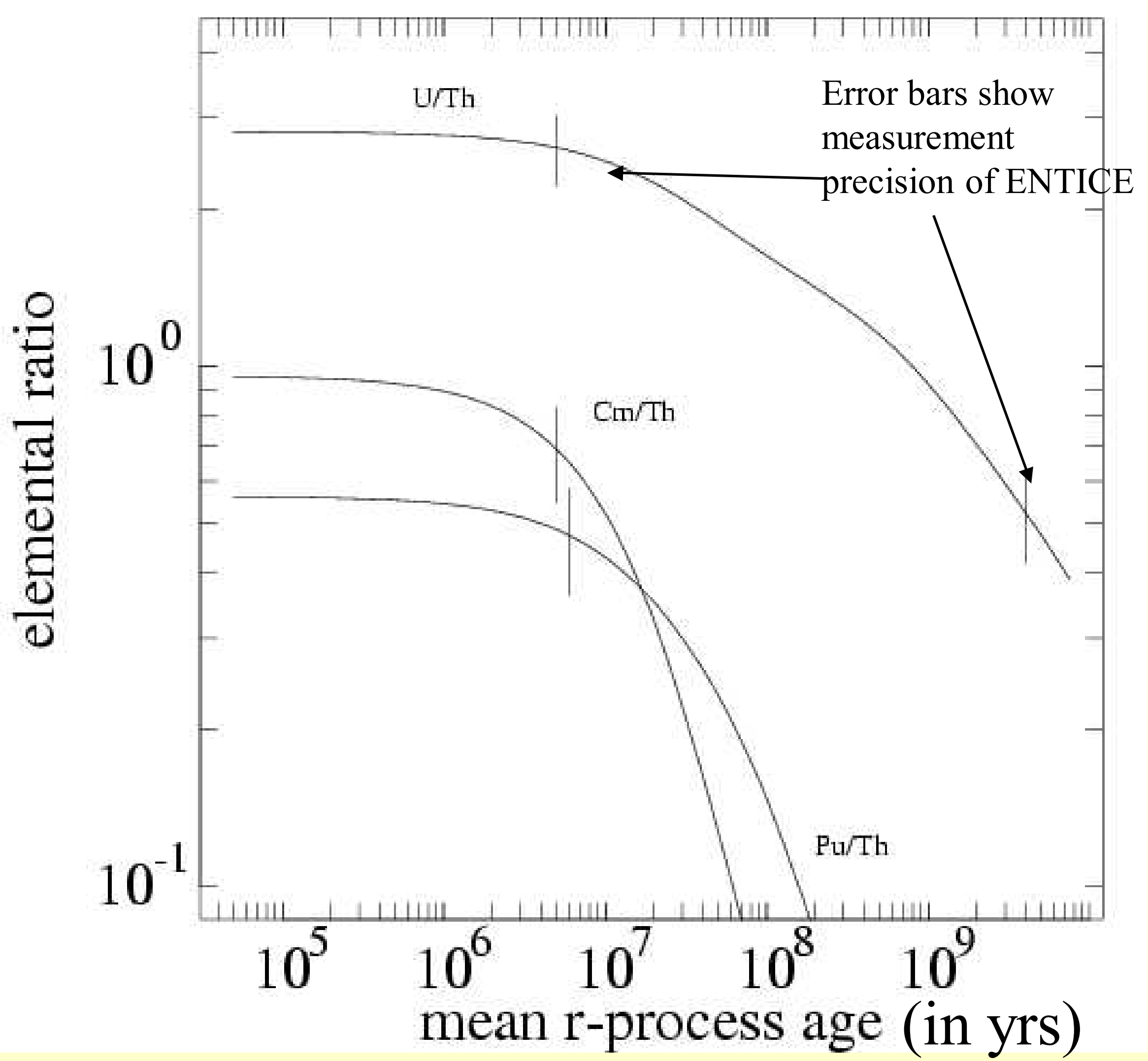
N44 Superbubble

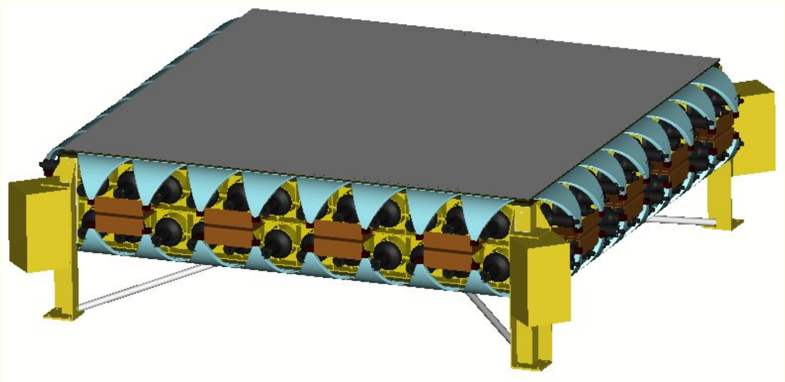
Credit: Gemini Observatory/AURA

What is the Signature of a Fresh Sample?

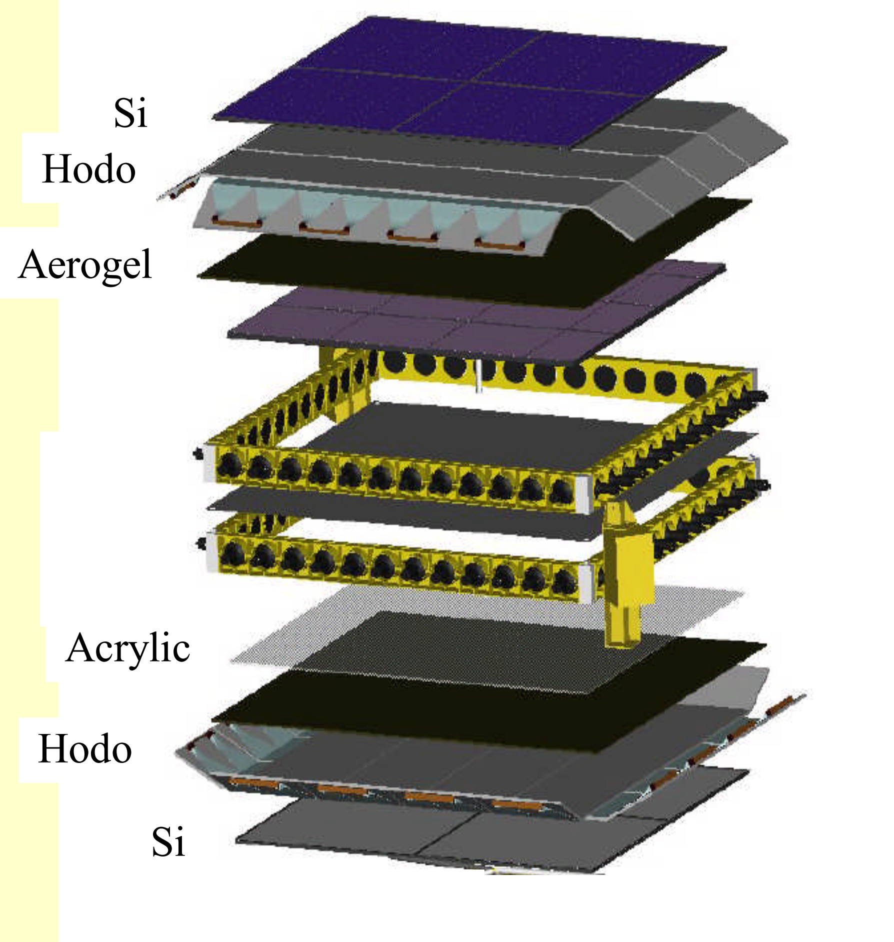
Actinides (Th, U, Pu, Cm) are clocks that measure absolute age of the sample

- Pu and Cm are “smoking guns” for fresh nucleosynthesis
- ENTICE is sensitive to as little as <2% admixture of r-process material at the 3σ level





ENTICE Instrument



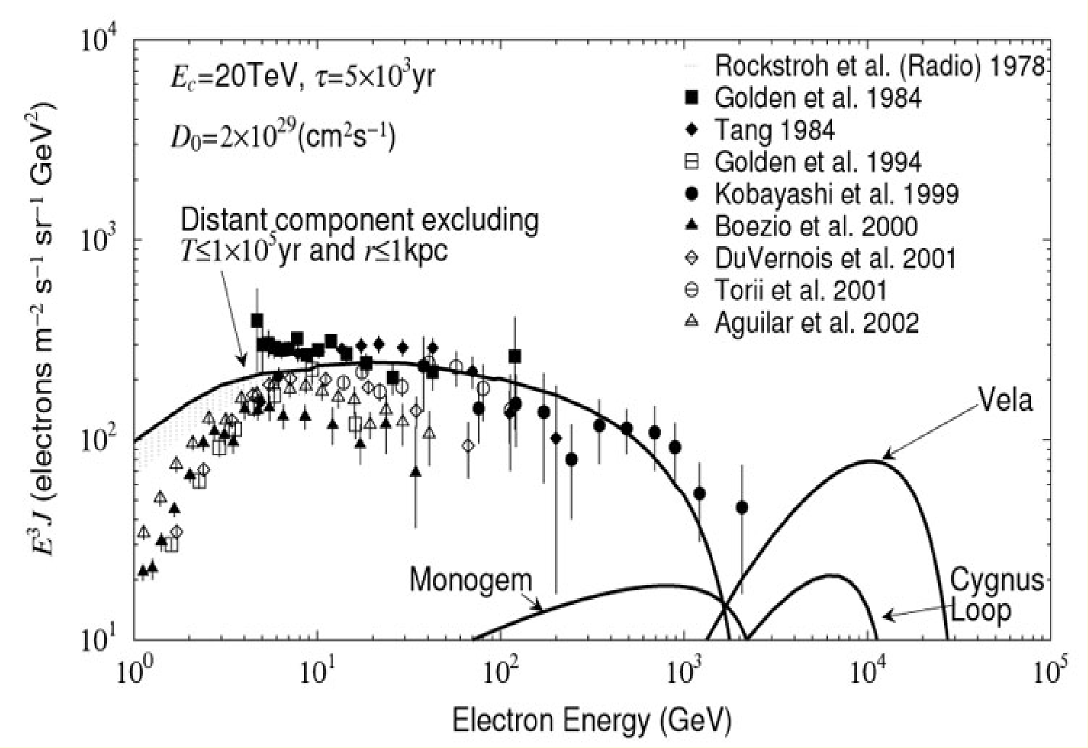
- Four identical ENTICE modules
- Detector vol. 2m x 2m x 50cm x 4 modules
  Mass: 2000kg   Power: 310W Bit rate: 40kbps
- Three kinds of detectors, each with extensive flight heritage.
  - 800 silicon detectors/module-dE/dx
    - Two layers, one top and one bottom
  - 2 Cherenkov detectors, each 2 m x 2 m
    - Each viewed by 48 five-inch photomultipliers
    - acrylic rad., n = 1.5; aerogel rad., n=1.04
  - Scintillating fiber hodoscope, x,y top & bottom
    - 0.5-mm fibers, 4-mm segmentation
    - Coded readout, eight 16-anode PMTs each side

Heritage: HNX Phase A Study and TIGER balloon flights

HEPCaT: Electrons can provide additional information about the GCR source

- High energy electrons have a high energy loss rate $\propto E^2$
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - Implies that source of high energy electrons are < 1 kpc away

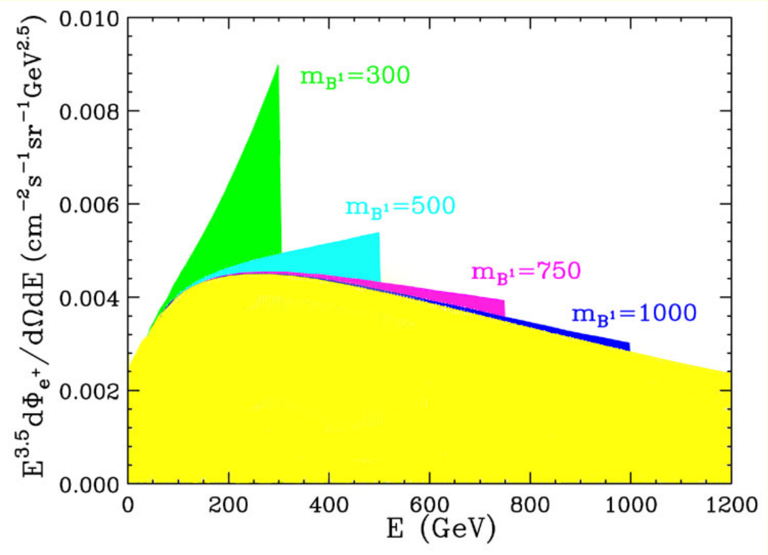
- Electrons **<u>are</u> accelerated in SNR** (as seen in γ-rays)
- Only a handful of SNR meet the lifetime & distance criteria
- Kobayashi et al (2004) calculations show structure in electron spectrum at high energy
- HEPCaT has the statistics to identify local sources.



Electrons may show “signature” of Dark Matter

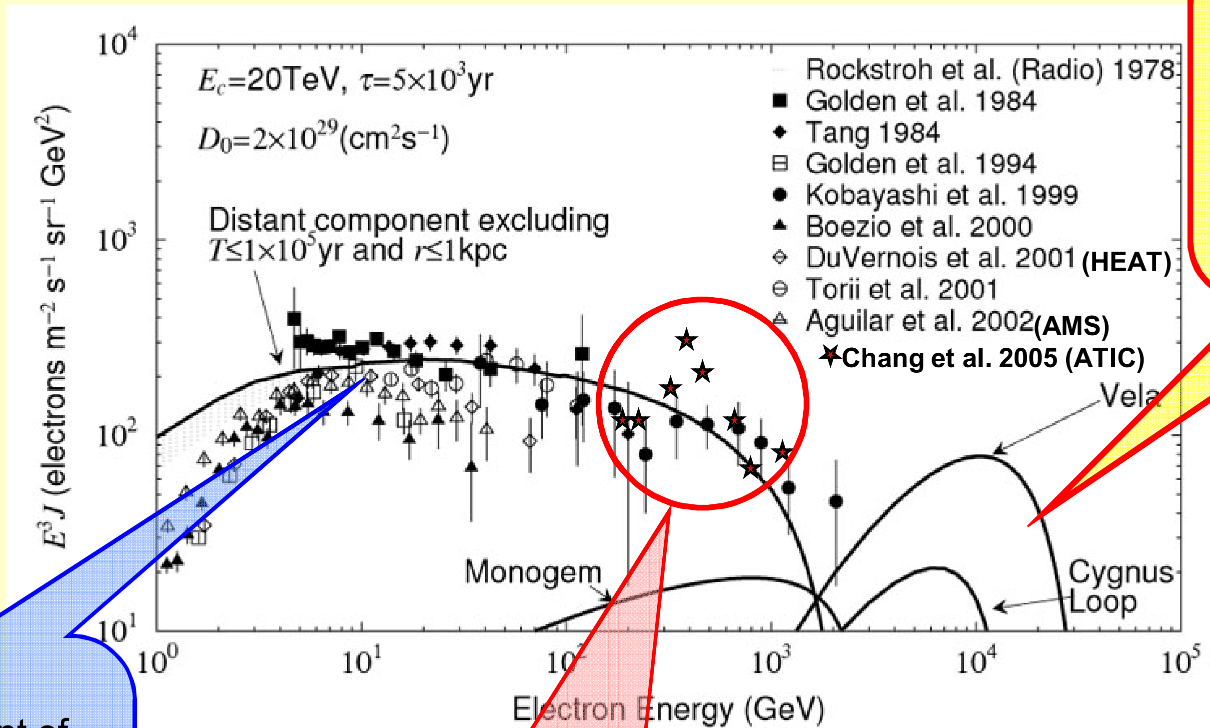
- Existence of dark matter is now widely accepted, but its exact nature remains a major mystery
- Over last several decades all known particles have been eliminated as dark matter candidates.
- Only a few exotic species such as neutralinos and Kaluza-Klein (KK) particles remain as candidates.

- Neutralinos can annihilate to produce e^+, e^- but not at a very high rate.
- Direct annihilation of KK to e , e^- is not suppressed and might produce an observable “feature” in the 150 – 800 GeV electron energy spectrum



Predicted KK annihilation positron signal by Cheng, Feng and Matchev (2002)

SUMMARY: What can be learned from HE electrons (> 10 GeV) ?



Search for the signature of nearby HE electrons sources (believed to be SNR) in the electron spectrum above ~ TeV

Search for anisotropy in HE electron flux (see e.g. Ptuskin & Ormes, XXIV ICRC, Rome, 1995 : nearby sources, streaming of local magnetic fields?

Precise measurement of electron spectrum above 10 GeV (calibration of IC gamma ray flux model, GALPROP)

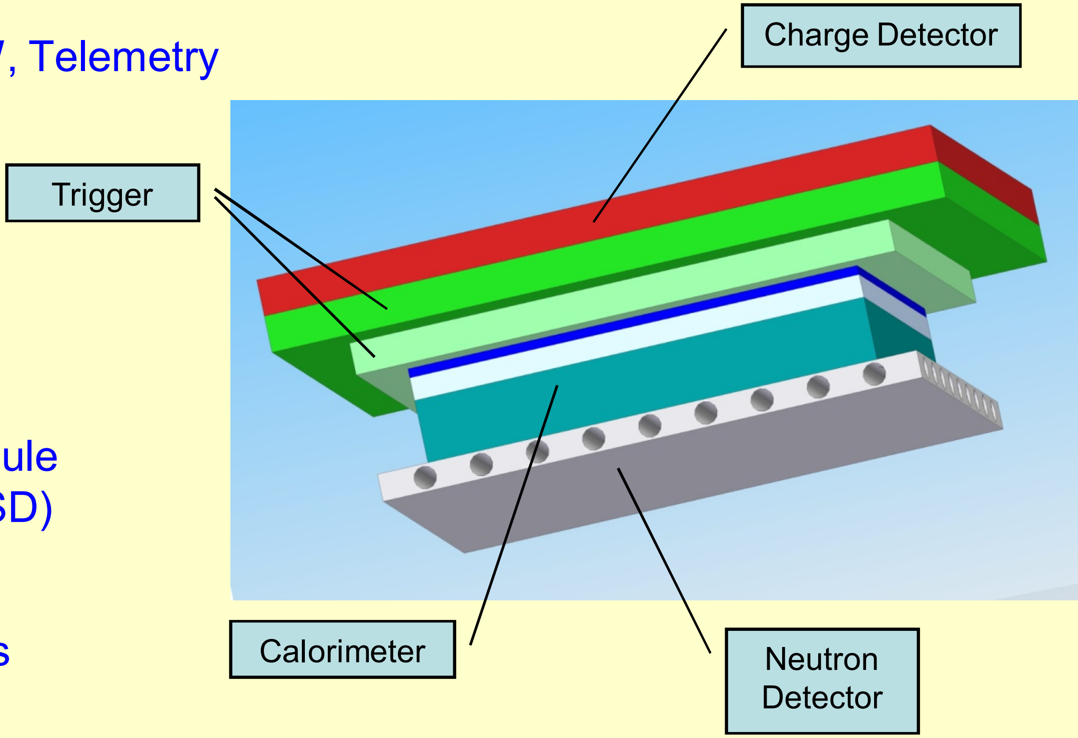
Search for Dark Matter Signatures (KKDM) – above ~100 GeV (see e.g. Baltz & Hooper, 2004)

What questions can be answered with the elemental composition at high energies?

- Do cosmic ray protons come from ordinary SNe exploding into the ISM while Z>1 nuclei come from massive stars exploding into their own stellar wind (Biermann et al)?
- Is the composition dominated at high energies by acceleration in young OB associations (Bykov, 2001)?
  - These questions can be answered by measuring the P, He and Fe composition.
- Are cosmic ray sources shrouded by super-bubble shells or dense stellar winds?
- Is there evidence of re-acceleration?
  - Both these points can be investigated by measuring the B/C ratio.

HEPCaT Instrument

- **Two identical HEPCaT modules**
  - Each module 1 m^2 ster
  - 1.4 m x 1.4 m x 0.6 m each
  - Total Mass: 4600 Kg, Power 700 W, Telemetry 160 kbps
- **Charge detector**
  - Two layers of Si pixel detectors
  - Near 100% area coverage
- **Trigger**
  - Two XY planes of scintillator strips
- **Calorimeter**
  - 80 cm x 80 cm active area per module
  - Tungsten and Si strip detectors (SSD) interleaved
  - Successive SSD layers rotated 90°
  - Total depth 40 X_0, 1.7 λ_I in 38 layers
  - Progressive absorber thickness:
    - 10 layers 0.2 X_0,
    - 4 layers 0.5 X_0,
    - 24 layers 1.5 X_0
- **Neutron Detector**
  - Borated scintillator



Summary

- OASIS will provide definitive answers to important scientific questions in a low risk mission
  - Do GCRs Come from OB associations?
  - Where does the GCR electron end and what will we find there?
  - What is the physical state of the GCR source material?
  - Do protons and heavier nuclei come from different sources?
- The OASIS mission has:
  - Clearly defined goals and requirements
  - Modest spacecraft engineering and mission needs
  - Instruments with balloon-flight heritage and previous Phase A and Mission Concept Studies
  - Spaceflight experience with all detector technologies.
  - Investigators with extensive experience collaborating on balloon and space flights.
  - Phase A–E cost of <$600M (including a 30% reserve)

Thank You